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Soil Catena Sequences and Fire Ecology in the Boreal Forest of Alaska

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ABSTRACT

This paper is the first to provide chemical, physical, and morphological properties of the soils in the boreal region of Alaska and to demonstrate the dominant effect of landscape attributes in soil formation. This study was conducted to characterize soils and landscape relationships in the boreal forest of Alaska. Sites representing major landform positions and vegetation communities were selected for study. Well-drained, shallow to moderately deep Inceptisols occur on the drier and warmer south aspect slopes with thin (5–9 cm) organic horizons and loamy textures. Poorly drained Gelisols form on wet and cold north aspect slopes and valley floors with thick (18–52 cm) organic horizons and permafrost within 45 to 60 cm of the surface. On the latter, mineral horizons are reduced. Soils on the ridgetop show features of relic, nonsorted circle (a type of pattern grounds) that indicate a previous periglacial environment. The mineral soil on backslopes is shallow to moderately deep due to gelifluction and slope movement but deep toward toeslopes. Charcoal particles, commonly found within the soil profiles, attest to frequent fire events in the past. Fire has the greatest impact on soil properties on south aspect slopes because the organic horizons are thin and dry, and easily destroyed by fire. The underlying mineral horizons often develop hydrophobicity resulted from moderately and severe burn. Slope, aspect, and slope gradient are major controlling factors for the contrasting soil types along the catena sequences in the watershed.

Jenny's functional-factoral soil formation model (Jenny, 1941) identifies the major components of pedogenesis to be parent material, organisms, topography, climate, and time. These factors tend to be highly interdependent and difficult to isolate in natural settings. Landscape topography dictates microclimate, water dynamics, and material redistribution processes that critically influence the nature of soils and vegetation mosaics (Hole and Campbell, 1985; Hunckler and Schaetzl, 1997). Slope gradient and aspect strongly affect soil morphological characteristics and geochemical processes in midlatitude (40–60°) settings (Lee and Baumgartner, 1966). Previous studies have investigated slope-differentiated catenae within these latitudinal constraints (Finney et al., 1962; Stepanov, 1967; Franzmeier et al., 1969; Macyk et al., 1978; Marron and Popenoe, 1986). In boreal regions where solar angles are low, the orientation of slope relative to peak solar influx plays an important role in the ecological energy budget (Péwé, 1975; Van Cleve et al., 1992). To quantify soil development under contrasting slope-influenced energy regimes in a boreal setting, individual soil profiles must be characterized as catena sequences on slopes of similar topography but different aspects. The empirical data can be used to build a model of topographically influenced subsoil variability in boreal regions strongly affected by fire and may also help predict changes brought about by prescribed burning.

The Caribou-Poker Creek Research Watershed (CPCRW), located 50 km northwest of Fairbanks, Alaska (Fig. 1), is within the discontinuous permafrost zone that extends across central Alaska eastward into north-central Canada. The watershed is representative of non-glaciated upland headwater stream basins found throughout interior Alaska. Forest communities in the watershed are representative of the boreal forest zone in Alaska. Forest fire is a dominant ecological factor in this region (Kasischke and Stocks, 2000) and there has been wide interest in the effects of wildfires on forest ecosystem but little on soils. Quantitative, site-specific baseline soils data are essential for comparing pre- and postfire changes within and below the forest floor. Rieger et al. (1972) provide descriptions and maps (at a scale of 1:31 680) for seven soil series within the watershed; however, little quantitative data are provided. Viereck et al. (1983) addressed, in detail, the soils, vegetation, and their relationship along a toposequence at the Bonanza Creek Long-Term-Ecological-Research site 90 km to the southwest. The soils at Bonanza Creek developed on deep loess deposits associated with the nearby Tanana River and are not representative of the soils formed in the Yukon-Tanana Uplands metamorphic complex. Soils at Bonanza Creek watershed formed in deep loess deposits on the uplands and alluvium on the floodplains. Whereas, soils associated with the metamorphic complex of CRCRW formed in residuum weathered from acidic igneous rocks and are extensive in interior Alaska (Mulligan, 2005; Rieger et al., 1979). Thus, a need exists to describe the soils formed in residual material of this upland complex.

Objectives of this study were to: (i) provide detailed morphological and geochemical descriptions of landscape type-location soils, (ii) classify the soils using U.S. Soil Taxonomy (Soil Survey Staff, 2003) and FAO World Reference Base for Soil Resources (FAO, 1998), and (iii) predict soil response to fire within the watershed.

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Abbreviations: asl, above sea level; CPCRW, Caribou Poker Creek Research Watershed; CREEL, Cold Regions Research & Engineering Laboratory; SMR, soil moisture regime; STR, soil temperature regime.

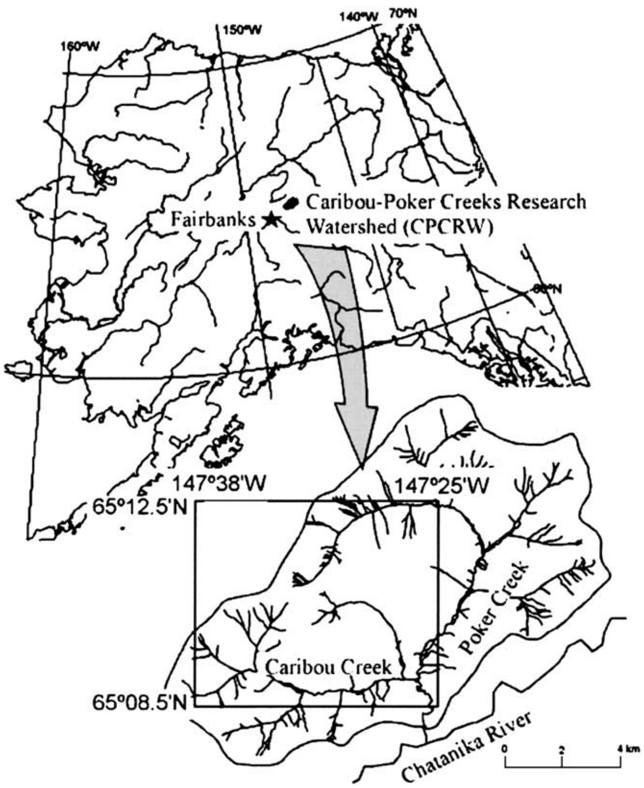

Fig. 1. Location of study area.

MATERIALS AND METHODS

Study Area

Physiography

The 104-km^2 CPCRW is located in the Yukon-Tanana Uplands of the Northern Plateau Physiographic Province in interior Alaska (Wahrhaftig, 1965) near the community of Chatanika and at 65°10′ N latitude and 147°30′ W longitude (Fig. 1). The Yukon-Tanana Uplands are comprised of a series of northeast-trending, round-topped ridges with valley floors that are relatively flat, filled with deep alluvial accumulations (Wahrhaftig, 1965). The CPCRW is a northeast-southwest trending ovate basin approximately 16 km long by 8 km wide. The Caribou Creek drainage comprises about 40% of the watershed and the Poker and Little Poker Creek drainages make up the remainder. Elevations range from 210 m above sea level (asl) where Poker Creek enters the Chatanika River to 826 m asl at the northern divide. Table 1 lists geographic locations and geomorphic properties of the soil study sites.

Geology

The Yukon-Tanana metamorphic complex (meta-sedimentary rocks formerly termed the Birch Creek Formation) underlies the CPCRW as well as approximately 75% of the Yukon-Tanana Uplands. Chapman et al. (1971) describe the complex within the CPCRW as the greenschist facies, dominated by chloritic and quartz-mica schists, with some micaceous quartzites, garnet-mica schists, phyllites, and possibly greenstone or impure marbles.

During Illinoian and Wisconsin glaciations (180–130 kA and 70–15 kA, respectively), silt and fine sand (loess) from the Tanana River was carried by southerly winds and deposited on the Yukon-Tanana uplands with thickest deposition occurring on south-facing slopes and on valley floors immediately adjacent to the Tanana River; in the CPCRW, only thin loess caps occur on the interfluves due to distance from the silt source (Rieger et al., 1963; Péwé, 1975; Viereck et al., 1983; Van Cleve et al., 1992). Small gelifluction lobes, subdued block fields, and tors provide evidence of past severe periglacial influences (Koutz and Slaughter, 1972). Resulting gelifluction and/or periglacial involution also affect pedogenesis. Most periglacial processes were initiated during the late Wisconsin cold phase maximum (Koutz and Slaughter, 1972; Jackson et al., 1999). Present soil morphogenesis is believed to have occurred during the Holocene.

Climate

The watershed has a continental climate with short warm summers and long cold winters. Climate trends are based on three weather stations within the study area: The Cold Regions Research & Engineering Laboratory (CRREL) station located on the valley floor at 225 m asl; the Caribou Peak station on the summit at 773 m asl, and the K20 station at 710 m asl on a north-facing slope about 200 m north of the Caribou Creek station. Climatic data, 8 yr (1995–2002) for two of these stations and 1 yr for K20 are provided in Table 2. Seasonal air temperature means at the three stations demonstrate how elevation and aspect influences microclimate in this landscape. Summer temperatures at the higher elevation Caribou Peak and K20 stations are cooler than those recorded at the CRREL station. Winter temperatures at the higher elevations are warmer due to air mass inversions. At the two higher-elevation stations, mean annual air temperature (MAAT), mean annual soil temperature (MAST), mean summer soil temperature (MSST), and mean winter soil temperature (MWST) are higher than at the lower-elevation CRREL station.

Permafrost

Interior Alaska lies between the Arctic and the Maritime zones (Ping and Moore, 1993) where permafrost is discontinuous to continuous and is "warm" with a mean annual soil temperature just below 0°C (Moore et al., 1993). Here, permafrost is very sensitive to climatic change and its depth and even its presence are controlled by the fire cycle and subsequent vegetation succession (Viereck, 1970) and management practices (Moore and Ping, 1989; Ping, 1987). Discontinuous permafrost distribution is a result of a combination of factors including nature of the regolith, vegetation cover, topographic microclimatological effects (e.g., variable solar incidence angles and inversion persistence), and drainage. Some permafrost is relic from a former climate (Péwé, 1975). Most permafrost is found on poorly drained floodplains and north-aspect backslopes and tends to restrict infiltration (Haugen et al., 1982). Because of the watershed's close proximity to the southern limit of permafrost, the permafrost is especially sensitive to regional climate, vegetation, and global climatic changes. Recent permafrost thawing due to climatic warming is evident in the region (Osterkamp and Romanovsky, 1999).

Vegetation

Plants were identified on each site by Dr. D.J. Helm, University of Alaska Fairbanks. Well-drained, south-facing slopes support mixed forest stands of paper birch (*Betula neoalaskansa* Sarg.) and young black spruce [*Picea mariana* (Mill.) B.S.P.]. Summits and shoulders support hardwood stands dominated by aspen (*Populus tremuloides* Michx.) with an alder [*Alnus viridis* (Vill.) DC.] understory. Ground cover includes northern comandra [*Geocaulon lividum* (Rich.) Fern.], wild red currant (*Ribes triste* Pall.), lingonberry (*Vaccinium vitis-idaea* L.), blueberry (*Vaccinium uliginosum* L.), stiff clubmoss (*Lycopodium annotinum* s.l.), polytrichum moss (*Poly-*

Table 1. Physical environment of the soil study sites in the Caribou–Poker Creek Research Watershed, interior Alaska.

Site no.	Lat. Long.	Elev. m	Landform	Landscape position	Parent material	Slope % shape	Aspect °	Landcover type	Drainage
					North Catena sites				
1	65°09′06″ N 147°29′14″ W	217	valley	valley floor	alluvium	8 hummocky	190	black spruce forest	very poorly
2	65°11′04″ N 147°28′48″ W	302	valley	toeslope	alluvium	6 hummocky	105	tussock tundra	poorly
3	65°10′34″ N 147°31′23″ W	383	hills	footslope	colluvium	50 hummock	0	black spruce forest	poorly
4	65°10′31″ N 147°31′24″ W	394	hills	footslope	colluvium	55 hummocky	15	black spruce forest	poorly
5	65°11′42″ N 147°29′51″ W	760	hills	backslope	loess/colluvium	14 convex	345	black spruce forest	poorly
6	65°11′35″ N 147°29′55″ W	773	hills	summit	residuum	1 convex	330	alpine tundra	well
					South Catena sites				
7	65°10′16″ N 147°30′50″ W	390	hills	shoulder	loess/residium	18 convex	210	birch forest	well
8	65°10′01″ N 147°26′48″ W	385	hills	backslope	loess/colluvium	19 convex	110	mixed aspen & white spruce forest	well
9	65°09′49″ N 147°30′12″ W	312	hills	backslope	loess/colluvium	28 hummocky	45	white spruce	moderately well
10	65°10′18″ N 147°30′35″ W	305	hills	footslope	loess/colluvium	22 plane	220	mixed aspen & white spruce forest	well

trichum commune L.), and assorted forbs. North-facing slopes and alluvial fans support open black spruce stands with willows (*Salix* spp.), alder (*Alnus* spp.), dwarf birch (*Betula glandulosa* Michx.), blueberry, Labrador-tea (*Ledum groenlandicum* Oeder), arctic dock (*Rumex arcticus* Trautv.), small bog cranberry (*Oxycoccus microcarpus* Turcz.), red-berry bearberry [*Arctostaphylos rubra* (Rehd. & Wils.) Fern.], cloudberry (*Rubus chamaemorus* L.), clubmoss (*Lycopodium clavatum* L.), Sphagnum spp., and schreber's big red stemmed feathermoss [*Pleurozium schreberi* (Brid. Mitt.)]. Vegetation on the tussock floodplain includes cottongrass (*Eriophorum* spp.), blueberry, Labrador-tea, dwarf birch, cloudberry, *Sphagnum* spp., schreber's big red stemmed feathermoss, and scattered, stunted black spruce.

Field Study

Site Selection

Ten soil-sampling sites were selected to represent the major landforms and forest cover types in the watershed. Sample site physical environment characteristics are provided in Table 1 and relative locations are shown in Fig. 2.

Table 2. Soil climate of the Caribou-Poker Creeks Research Watershed, interior Alaska.†

Year	TAP	MAAT	MAST	MSST	MWST	FFD	Active layer	Max. snow depth
	mm	°C				d	cm	
		CRREL Station, Elev. 218 m (Lat. 65°09′18″ N; Long. 147°29′15″ W)						
1995	325	−4.7	−1.2	−0.3	−0.9	182	69	69
1996	339	−6.3	−3.4	−0.5	−6.8	153	68	53
1997	227	−3.9	−2.9	−0.4	−6.4	170	68	56
1998	331	−3.2	−2.5	−0.2	−6.3	146	68	51
1999	292	−4.0	−1.1	−0.8	−2.6	162	46	39
2000	404	−3.2	−2.5	0.8	−6.1	189	38	66
2001	347	−3.6	−2.7	2.1	−7.4	189	46	51
2002	367	−2.4	−2.8	−1.8	−3.7	190	46	31
2003	526	−3.0	−1.7	−0.8	−2.3	nd	52	60
Ave.	351	−3.8	−2.3	−0.2	−4.7	173	56	53
		K20 Station, Elev. 710 m (Lat. 65°11′44.7″ N; Long. 147°29′51″ W)						
1998	–	−2.1	−0.1	−0.2	1.4	194	1441	75
		Caribou Peak Station, Elev. 773 m (Lat. 65°11′31.51″ N; Long. 147°29′53″ W)						
1995	368	−0.3	nd	nd	nd	194	>400	86
1996	520	−2.4	nd	nd	nd	157	>400	56
1997	236	nd	nd	nd	nd	nd	>400	71
1998	345	−0.2	nd	nd	nd	169	>400	56
1999	328	−2.5	0.05	2.1	−1.1	163	>400	56
2000	291	−1.3	0.64	1.7	−0.4	202	>400	97
2001	384	−1.3	0.86	2.4	−0.6	223	>400	61
2002	457	−0.1	−0.02	1.1	−1.2	200	>400	nd
2003	422	−1.4	0.50	1.0	−0.1	nd	>400	66
Ave.	372	−1.2	0.40	1.7	−0.8	187	>400	69

† TAP, total annual precipitation; MAAT, mean annual air temperature; MAST, mean annual soil temperature; MSST, mean summer soil temperature; MWST, mean winter soil temperature; FFD, frost free days.

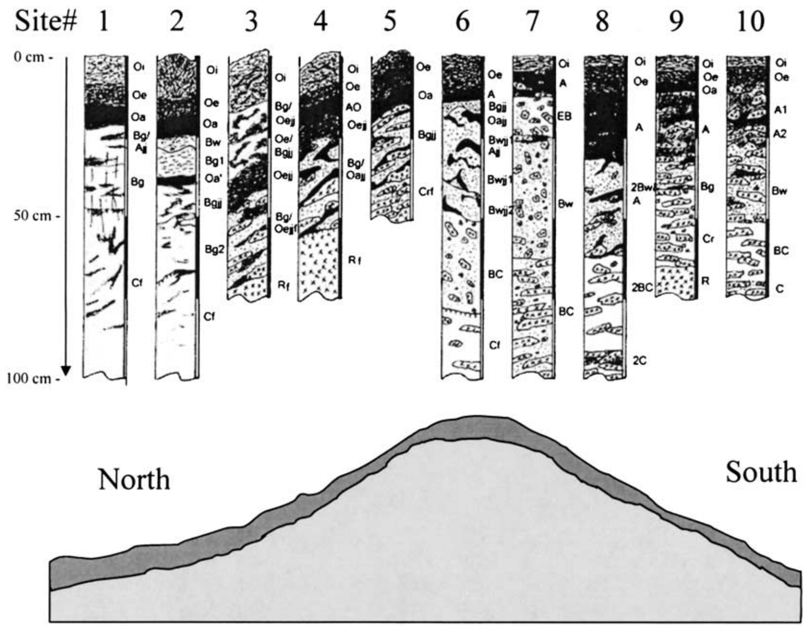

Fig. 2. Site soils in relation to landscape position.

Soil Profile Description

Soil pits, 1 m × 0.6 m, were excavated to >1-m depth or a paralithic/lithic contact. Morphological properties were described using the standard terminology of the Soil Survey Manual (Soil Survey Division Staff, 1994). Field descriptive data are provided in Table 3.

Soil Sampling and Characterization Analysis

Soil physical and chemical analyses were conducted at the Alaska Agricultural and Forestry Experiment Station, Palmer Research Center laboratory using USDA National Soil Survey Laboratory procedures (Soil Survey Laboratory Staff, 1996). Bulk density samples were taken in the field using a core of 30 cm^3 and calculated on an oven dry basis (105°C). Particle-size distribution was determined by hydrometer after organic matter was removed by hydrogen peroxide treatment. Soil pH was measured in both distilled water (1:1) and 0.01 *M* $CaCl_2$. Total C and N were determined in duplicates with a LECO 1000 CHN Analyzer LECO Corp., St. Joseph, MI). Soil samples with pH values >5.5 were pretreated with 1 *M* HCl to remove inorganic C. Cation exchange capacity and exchangeable cations (Ca, K, Mg, and Na) were determined by extracting the soil samples with ammonium acetate solution (1 *M*, pH 7); the residue was steam distilled for CEC measurement and solutions were analyzed for the cations using an inductively coupled plasma optical emission spectrometer (ICP–OES). Exchange acidity was determined using $BaCl_2$ (buffered at pH 8.3) extraction followed by HCl titration. Iron and Al were selectively extracted with buffered dithionite-citrate (total extractable Al/Fe or Al_d/Fe_d) (Mehra and Jackson, 1960), ammonium oxalate at pH 3.5 [poorly crystalline and organically bound Fe and Al (Fe_o and Al_o)] (Schwertmann, 1964), and Na-pyrophosphate solution at pH 10 [organically bound Fe and Al (Fe_p and Al_p)] (McKeague and Day, 1966) with ICP–OES analysis of all extracts. Ratios of these pools serve as proxy indices of alteration intensity (Blume and Schwertmann, 1969; Parfitt, 1983). Soil morphological properties of the 10 sites are provided in Table 3. Soil profile descriptions together with soil physical and chemical properties are posted on the permanent Long Term Ecological Research (LTER) web page: http://www.lter.uaf.edu (verified 28 June 2005).

RESULTS AND DISCUSSION

In the Fairbanks area, sediments of early to late Pleistocene were deposited in valley bottoms and on older terraces, but the modern soils formed in Holocene deposits (Péwé, 1975; Sellman, 1967; Brown and Kreig 1983). Although the study area was not glaciated, there is no evidence of paleosols on the uplands. It is reasonable to assume that any evidence of paleosols on slopes was erased by active mass movement and gelifluction processes. Thus, the modern soils in the study area are presumed to be of Holocene age. Silt loam textures in some surface mineral horizons (particularly south-aspect slopes) are attributed to loess accumulations as evidenced by their silt content (Table 3).

Soil Morphology

Results of the soil morphological study are discussed according to aspect on the catena (Table 3). The study sites in Tables 3 and 4 are arranged according to their spatial positions on the catena from flood plain (valley bottom) up the north slope to the ridge then to the south slope downward (Fig. 2).

South Aspect Catena

Horizonation in soils of the south aspect consists of shallow organic (O) horizons (5–15 cm) overlying thick A and B sequences that grade into grayish brown BC horizons and fractured bedrock. Generally, these soils are relatively coarse textured, dominated by sand- and silt-size fractions and low clay contents. The weak subangular structure of the mineral horizons indicates no seasonal moisture deficits. Low clay and moderate silt contents render most of the soil consistencies as friable or very friable under field moist conditions and are only slightly sticky and slightly plastic when wet. Early summer moisture content by weight of the organic and mineral horizons average 283% (range 122–499%) and

Table 3. Morphological properties of soils in the Caribou-Poker Creek Research Watershed, Alaska.†

Site & horizon	Depth	Munsell Color (moist)	Field texture‡	Particle size§ Sand	Silt	Clay	Structure¶	Consistency# Moist	Wet	Roots††	Bulk density	% Rock fragment	Boundary‡‡
	cm			—— % ——							Mg m^{-3}	>2 mm	
North Catena sites													
1. Floodplain: Coarse-silty, mixed, superactive, subgelic Typic Histoturbels (Histic Cryosols)													
Oi	0–8	10YR 4/6,4/4	PT	nd	nd	nd				3VF,F, 2M		0	CS
Oe	8–16	7.5YR 2.5/3	PT MK	nd	nd	nd	1MPL			3VF,F, 2M,1C		0	AS
Oa	16–23	7.5YR 2.5/1	Muck	nd	nd	nd	(sat'd)	nd	SS PO	2VF,F, 1M		0	AS
Bg/Ajj	23–36	5Y 3/3, 4/2 10YR 3/3	Bg-SIL A-MkSIL				(sat'd)	nd	SS SP	1VF,F		0	AS
Bg2	36–55	5Y 3/2	SIL				3VNpl	VFI	SS SP			0	CS
Cf	55–107	5Y 4/1	SIL				3VNpl	XR	SS SP			0	
2. Toeslope: Coarse-silty, mixed, superactive, subgelic Ruptic-Histic Aquiturbels (Histic-Turbic Cryosols)													
Oi	0–13	7.5YR 4/3	GS PT	nd	nd	nd				3VF,F,M,C	0.03	0	CS
Oe	13–18	7.5YR 3/4	MK PT	nd	nd	nd				3VF,F,M	0.15	0	CI
OA	18–26	10YR 2/1	MK	nd	nd	nd	1FGR	VFR	SOP	3VF,F, 2M	0.90	0	CI
Bw	26–29	7.5YR 3/3	FSL	25	68	7	1FGR	VFR	SSSP	2VF,F	0.97	0	AS
Bg1	29–38	2.5Y 3/2	SIL	25	68	7	2TNPL	FR	SSSP	2VF,F	0.97	0	AS
Oa'	38–40	7.5YR 2.5/1	MK	nd	nd	nd	1FSBK	FR	SSSP	2VF,F	0.43	0	AS
Bgjj	40–53	2.5Y 3/2 (55%) 5YR 4/3 (30%), 2.5Y 6/1, 2/2	FSL	14	74	12	2TNPL	FR	SSSP	2VF,F 3F RR/RC	1.27	0	AI
Bg2	53–70	2.5Y 3/2, 10YR 3/3, 7.5YR 5/8, 2.5Y 6/1	SIL	16	72	12	1TNPL	FR	SSSP	3F RR	1.12	0	AI
Cf	70–118	7.5YR 3/2, 7.5YR4/6 RC	PF-SIL	24	66	10	3VNPL 3VN ICE	VR	SSSP	3F RC	1.07	0	
3. Footslope: Dysic, subgelic Lithic Hemistels (Gelic Histosols)													
Oi	0–16	7.5YR 4/4	PT	nd	nd	nd				3VF,F 2M	0.07	0	AS
Bg/Oejj	16–28	7.5YR 2.5/2 10YR 2/2	PT MK SIL	46	50	4		FR	SS SP	2VF,F	0.47	0	AI
Oe/Bgjj	28–43	7.5YR 2.5/3 10YR 2/2	PT MK MK SIL	nd	nd	nd	1MPL	FR	SS SP	1VF,F	0.41	0	AI
Oejj	43–52	7.5YR 3/3	MK PT	nd	nd	nd	IMPL			1VF,F	0.22	0	AI
Bg/Oejjf	52–70	10YR 2/2	ST MK SL	55	42	3	1MPL	FR	SS PO		0.40	0	AS
Rf	70+												
4. Footslope: Dysic, subgelic Lithic Hemistels (Gelic Histosols)													
Oi	0–14	7.5YR 4/6	PT	nd	nd	nd				3VF,F, 2M	0.04	0	AS
Oe	14–18	10YR 2/1	PT MK	nd	nd	nd				3VF,F, 1M	0.07	0	CW
AO	18–23	10YR 3/2	MK SIL	39	58	3		FR	SS SP	1F	0.29	0	AI
Oejj	23–30	7.5YR 3/2	PT MK	nd	nd	nd	3TNPL	VFR	SOPO		0.18	0	AI
Bg/Oajj	30–55	10YR 3/3	CH MK SIL	59	35	6	3TNPL	FR	SSSP		0.42	65 CH	
Rf	55+												
5. Backslope: Loamy-skeletal, mixed, superactive, subgelic Lithic Aquiturbel (Histic Cryosol)													
Oe	0–15	7.5YR3/4	MKPT	nd			nd			3VF,F,2M 3C	0.20		CI
Oa	15–19	10YR 2/1	MK	nd			MA	VFR	S O PO	3VF,F,1C			AI
Bg	19–40	5YR4/2; 2.5Y 4/4 (5%)	CNVL	42	45	14	MA (Sat'd)	FI M	S SP	2F		55	CW
Crf	40–50	5Y 4/2	FLXL	42	45	14	MA (Frozen)	EF	SS SP	0		70	
6. Summit: Coarse-loamy, mixed, superactive, subgelic Aquic Haploturbels (Turbic Cryosols)													
Oe	0–11	7.5YR 2.5/3	MKPT	nd			nd	nd		3F,M,C	0.18		AI
A	11–13	10YR 3/3	L	nd			2MGR	FR	SS SP	3VF,M	0.98		AS
Bgjj	13–14	5Y 4/2, 2.5 Y 4/4 (30%)	SL	42	44	14	MA	FR	SS SP	2VF,F	1.4	12	CI
Bwjj1	14–42	2.5Y 4/4	SL	37	49	14	1THLT	FI	SS SP	0		17	CI
Bwjj2	42–53	2.5Y 4/3; 5Y 4/2 (5%) 10YR 4/6 (5%)	SL	45	43	12	3FLT 3MLT	FI	SS SP	0		10	CI
Oajj	13–20	10YR 2/2	MKSL	nd			MA	VFR	SO PO	2VF		38	AI
Ajj	26–30	10YR 3/2	SL	41	45	14	1FGR	VFR	SS SP	3VF		19	CI
BC	53–80	2.5Y 4/3	GRSL	45	40	16	1FLT	FR	SS SP	0		20	CS
Cf	80–105	5Y 4/3	GRSL	50	36	14	MA (frozen)	EF	SS SP	0		30	
South Catena sites													
7. Shoulder: Coarse-loamy, mixed, superactive, subgelic Typic Dystrocryepts (Dystric Cambisols)													
Oi	0–5	7.5YR 3/2	PT	nd	nd	nd	1TNPL			3vf,f,m,1c	0.07	3	CS
A	5–13	10YR 3/2	GRVL	31	52	17	1FSBK to 1FGR	FR	SS SP	3VF,F,M,1C	0.47	49	CW
EB	13–25	2.5Y 4/2	GRVL	45	46	9	1TNPL	VFR	SS SP	2VF,F, 1M,C	1.17	42	GS
Bw	25–63	2.5Y 4/3	GRVGL	35	54	11	1MSBK to 1FABK	FR	SS SP	1F,M	1.47	36 GR 10 CH	GS
BC	63–105	2.5Y 4/3	CHVSL	39	48	13	2TNPL	FR	SS SP	1F,M	1.29	20 CH 18 GR	
8. Backslope: Coarse-loamy, mixed, superactive, subgelic Typic Dystrogelepts (Dystric Cambisols)													
Oi	0–3	10YR 3/2	PT	nd	nd	nd	1TNPL	VFR	SOPO	3VF,F	0.04	5	AS
Oe	3–12	7.5YR 2.5/2	MK PT	nd	nd	nd	1TNPL to 1FGR	VFR	SOPO	3VF,F,M, 1C	0.14	5	AS
A	12–32	2.5Y 4/2	VFSL	44	51	5	1FGR	VFR	SSMP	3VF,F, 2M,C	0.85	10	CS

Continued next page.

Table 3. Continued.

Site & horizon	Depth	Munsell Color (moist)	Field texture‡	Particle size§ Sand	Silt	Clay	Structure¶	Consistency# Moist	Wet	Roots††	Bulk density	% Rock fragment	Boundary‡‡
	cm			—	% —						Mg m^{-3}	>2 mm	
2Bw&A	32–62	7.5YR 5/3	GRVSL	56	36	8	2THPL,	VFR	SSMP	2VF,F, 1M	1.09	37 GR	
		10YR 4/4 (13%)					1FSBK					10 CN	DI
2BC	62–92	10YR 4/3	CBVSL	54	37	9	2FSBK	FR	SSMP	1VF	1.09	19 GR	
												20 CH	CS
2C	92–112	2.5Y 4/4	CBVSL	47	40	13	1TNPL	VFR	SSSP		1.10	32 GR	
												20 CH	CS
							South Catena Sites						
9. Backslope: Loamy, mixed, superactive, subgelic Lithic Dystrogelepts (Dystric Cambisols)													
Oi	0–5	7.5YR 5/6	PT	nd	nd	nd				3VF,F, 2M	0.05	8	AS
Oe	5–9	10YR 2/2	MKPT	nd	nd	nd				2VF,F, 1M	0.05	8	AI
Oa	9–11	10YR 2/1	MK	nd	nd	nd				2VF,F, 1M	0.17	8	AS
A	11–31	10YR 3/3	CHSL	51	41	8	IMPL	FR	SS SP	2VF,F, 1M	0.90	25 CH	CS
Bg	31–41	2.5Y 4/4	CHVSL	55	37	8	2TNPL	FR	SS SP	1F	1.21	40 CH	CS
Cr	41–66	2.5Y 4/3	CHVL	54	38	8	M	FI	MSM P		0.96	65 CH	
R	66+												
10. Footslope: Loamy-skeletal, mixed, superactive, subgelic Humic Dystrogelepts (Dystric Cambisols)													
Oi	0–3	7.5YR 4/4	PT	nd	nd	nd				2VF,F,M	0.06	10	AI
Oe	3–7	7.5YR 2.5/2	PT MK	nd	nd	nd				3VF,F, 2M	0.46	10	AS
A1	7–22	10YR 3/4	KVSL	54	40	6	1FSBK	VFR	SS SP	3VF,F, 2M, 1C	0.80	60	AS
A2	22–29	10YR 3/3	CH SL	58	34	8	2FSBK	VFR	SS SP	3VF,F, 2M	1.23	40	CW
Bw	29–51	10YR 4/3	CHV SL	72	22	6	1FSBK	VFR	SS SP	2VF,F,M	1.63	40	DS
BC	51–70	2.5Y 4/3	CHV SL	74	22	4	1FSBK	VFR	SS SP	1VF,F	1.10	50	DS
C	70+	2.5Y 4/3	CHV SL	66	30	4	1MSBK	VFR	SS SP	1F RR	0.91	65	

† Abbreviations for soil morphological properties are from Schoeneberger et al., 2002.

‡ Field texture: PT: peat; MK PT: muck peat; VFSL: very fine sandy loam; GRVSL: very gravelly sandy loam; CBVSL: very cobbly sandy loam; GS PT: grassy peat; FSL: fine sandy loam; SIL: silt loam; PF-SIL: permanently frozen silt loam; CH MK: channery muck; ST MK SL: stony mucky sandy loam; CHSL: channery sandy loam; CHVSL: very channery sandy loam; CHVL: very channery loam; KVSL: very cobbly sandy loam; GRVL: very gravelly loam.

§ Particle size distribution, nd: not determined.

¶ Structure, 1THPL: weak thin platy; 2THPL: moderate, thin platy; 3TNPL: strong, thin platy; 3VNPL: strong very thin platy; 1MPL: weak, medium platy; 1FGR: weak, fine granular; 1FABK: weak fine angular blocky; 1FSBK: weak, fine subangular blocky; 2FSBK: moderate, fine subangular blocky; 2MSBK: moderate, fine subangular blocky; M: massive; 3VN ICE: strong very thin ice lens.

Consistency, VFR: very friable; FR: friable; FI: firm; VFI: very firm; VR: very rigid; MS: moderately sticky; MP: moderately plastic; SS: slightly sticky; SP: slightly plastic.

†† Roots, 3: many; 2: common; and 1: few; VF: very fine; F: fine: M: medium; and C: coarse; RC: root channels; RR: root remains.

‡‡ Boundary, AI: abrupt irregular; AS: abrupt smooth; CS: clear smooth; CW: clear wavy; DS: diffused smooth; GS: gradual smooth.

40% (range 10–116%), respectively. Aspen and birch occupy these well-drained, warmer south slopes. The fiber- and detritus-rich Oi or Oe horizons formed from the less decomposed litter have high tannin contents (Schimel et al., 2001). From the summit to the toeslope, soil organic horizon becomes thicker, and soil thickness increases with decreased rock fragments.

The upper shoulders around Caribou Peak are fragmental with bedrock exposed at the surface (Rieger et al., 1972). Below the rubble land, the well-drained and relatively warmer soils on the upper to lower backslopes (Sites 7 and 8) are generally deeper and more mineral-dominated than counterparts on the north aspect catena (Sites 2–4, Fig. 2). Rooting zones are limited to the O, A, and upper B horizons that contain maximum available nutrients and water. However, the deepest soils were found on the broad shoulder slopes at lower elevations with good drainage and in a relatively stable landscape position (Site 8). Deeper rooting zones enhance underground biomass volume and humic material storage (Table 3). From shoulder to footslope, most soils contain considerable rock fragments due to colluviation (i.e., 10–27% by volume in Site 7 vs. >50% at footslope Site 10). Irregular horizon boundaries and truncated horizons (i.e., Site 7) along with the high rock fragment content in the solum indicate that episodic slope failure and mass movement interrupted pedogenic progression. These truncated sequences also contain root remnants and root channels in some lower B and BC horizons that indicate burial of former surface layers.

North Aspect Catena

Soils formed on the broad summit (Caribou Peak) with very gentle north–facing slopes show relic features of nonsorted circles (Site 6). These soils have the typical "bowl" shaped morphology of soils associated with frost boils—remnants of A and Oa horizons frost-churned downward toward the bottom of the bowl (Ping et al. 2002a, 2002b). Inside the bowl, the Bg and Bw horizons are highly cryoturbated and the lowercase "jj" subordinate distinction is included after the horizon designations. These soils are relics of the periglacial environment since they show no evidence of current activity. On the surface, without excavation, the nonsorted circles cannot be separated from the intercircle area because of the vegetation cover. Below the summit, soils on north to east aspect slopes tend to be shallow with thicker organic horizons and discontinuous mineral horizons due to gelifluction (Sites 3–5, Fig. 2) than on south-facing slopes. They have much higher overall OC contents. Topographically induced microclimates for these landscape positions tend to be cooler than their south aspect counterparts that result in thick O horizons (20–50 cm) overlying weakly weathered, thin mineral horizons mixed with fractured bedrock. The fiber content in the

O horizons grade from discernible moss fibers to highly decomposed, mucky organic materials just above the mineral contact. Black spruce and mosses, well adapted to these wetter and cooler slopes, contribute considerably to the recalcitrant nature of the soil organic matter (SOM). Anaerobic conditions, as indicated by the positive reaction to α, α'-dipyridyl, in these poorly drained locations and the relatively colder soil temperatures limit SOM decomposition rates that result in thicker O horizons and also limit rooting depth to the lower boundary of the organic horizons. Similar rooting depth patterns were noted previously in boreal zone soils (Rieger et al., 1972; Furbush and Schoephorster, 1977). The majority of roots occur within these O horizons (Table 3). The platy structure, brought about by persistent seasonal frost in active layers and fluctuating permafrost tables in the lower active layer/and upper permafrost zones, dominates mineral horizons. Gelifluction or cryoturbation induce mineral/organic matter mixing as indicated by A/O or Bg/O horizons in some of the profiles. Wu (1984) found that ground movement on watershed slopes approaching 30° occurs only during early summer when soils are saturated and gelifluction is common. The thick O horizons on north-facing slopes functions as thick sponges that has have high porosity. These O horizons further insulate the mineral matrix and permafrost from surface influences. An aquic condition is commonly present on slopes even >50% as evidenced by their gray color and positive reaction to α, α'-dipyridyl that indicates the presence of ferrous iron (Childs, 1981). The reducing condition on steep slopes is likely due to saturation caused by slowly draining water from snowmelt in the thick organic horizons over frozen mineral horizons. Limited solar radiation onto this catena allows for snow to linger and extends snowmelt water supply later into the summer (Schaetzl and Isard, 1996) when biota draw down the oxygen and create reducing conditions. Water content ranges from 556 to 725% in O horizons and from 163 to 217% in mineral horizons. These values are three to five times higher than found in comparable horizons on the south aspect catena. The spread of values has broad implications for ecological responses of the two catenae to fire.

Although floodplain and toeslope soils (Sites 1 and 2) are shown as part of the catena (Fig. 2), they are within a cooler microclimate regime found in the valley bottoms and have limited drainage. Their soil morphology resembles that of north catena profiles with shallow depths to permafrost; but soils are relatively deep (>1 m) due to accumulations of fluvial sediments and tend to have finer textures, moderate to thick organic horizons, and fewer rock fragments. Poor to very poor drainage with associated reducing conditions produces the olive-gray (5Y 4/1–4/2) colored mineral horizons in these soils. Water-holding capacity, mediated by O horizons, is also comparable with those encountered on the north aspect catena. Wet consistencies were moderately sticky and plastic with inherent structures easily lost under compression and have poor trafficability when wet.

Chemical Characteristics

Topographically induced OM accumulation and leaching regimes are the primary influences on soil chemistry. In response to these factors, the catenae show strongly contrasting geochemical properties. Soil chemical data are provided in Table 4.

South Aspect Catena

Mean profile pH values decrease from the summit to the toeslope. On uplands pH values are generally slightly acidic and grade to very strongly acidic on the footslopes. The slightly lower pH values found in A horizons (Table 4) indicate organic acid translocation downward into the leached mineral matrix. In BC or C horizons pH values increase with depth and approach typical values of non-calcareous greenschist lithologies. This pH–depth relationship indicates the limited buffering capacity of the bedrock parent material and the abundance of organic acids in this catena. Exchange acidity (Ex-H^+, cmol kg^{-1} soil) is highly correlated with organic carbon (OC, kg Cm^{-3}) stocks ($R^2 = 0.83$, $P = 0.01$) because the decomposed SOM provides and occupies exchange sites. Exchange acidity values of the south aspect catena soils range from 26 to 71 cmol H^+ m^{-2}. An approximate pedogenic maturity index based on the ratio of Ex-H+ to volumetric weight content of OC provides values of 6 to 10 cmol H^+ kg OC^{-1} m^{-2} (Harden and Taylor, 1983).

Organic matter also controls CEC, extractable cations, and base saturation levels (BSat, the ratio of extractable cations to CEC) for all soils in the watershed. Since CECs are correlated with OC contents ($R^2 = 0.93$, $P <$ 0.0001), SOM provides most of the exchange sites. Loess deposition and humate complexation were responsible for elevated concentrations of Ca and Mg in the surface O horizons. Extractable Ca and Mg increase with depth and BSat is relatively high (>75%) indicating limited leaching in the solum. Increasing pH and decreasing extractable Ca and Mg with depth as well as lower BSat in soils on the mid- to lower backslopes (Sites 9 and 10) indicate more effective leaching in the lower slopes than on the interfluves and shoulders. Higher base saturation levels in C horizon are due to attenuated leaching regimes.

Total Fe_d contents in the well-drained south aspect soils are relatively high with Fe_o/Fe_d ratios approaching unity. This indicates that nearly all the Fe is present as either organically bound or short-range order oxyhydroxides. Strongly acidic tannins, released during Populus litter decomposition, promote weathering of primary minerals in surface mineral horizons. The regular decrease of Fe_o/Fe_d , Fe_p/Fe_d, and Al_p/Al_o ratios with depth in these soils indicates the presence of more finely crystalline primary Al and Fe forms and decreased humus complexation.

North Aspect Catena

Soils of the north aspect catena have overall lower pH values, higher OC contents, and depleted base status than the south aspect catena. These organically enriched

Table 4. Chemical properties of selected soils of the Caribou Poker Creek Watershed Research Area, Alaska.†

Site horizon	Depth	pH CaCl$_2$ 1:10	pH H$_2$O 1:1	OC	TN	Extractable bases Ca	Mg	K	Na	Ex. H$^+$ pH 8.2	CEC pH 7	Base sat.	Extractable Al, Fe, and Si Fe$_d$	Al$_d$	Fe$_o$	Al$_o$	Si$_o$	Fe$_p$	Al$_p$
	cm			— g kg^{-1} —		cmol kg^{-1}						%	g kg^{-1}						
North Catena sites																			
1. Floodplain																			
Oi	0–8	3.8	4.1	489	9	28.8	12.4	2.0	0.1	93	96	45	–	–	–	–	–	–	–
Oe	8–16	3.9	4.4	441	18	29.8	10.1	0.5	0.1	96	112	36	–	–	–	–	–	–	–
Oa/A	16–25	4.1	4.5	365	15	21.0	6.7	0.3	0.1	105	100	28	–	–	–	–	–	–	–
Bg1	25–36	4.1	4.8	46	2	4.7	1.5	0.1	0.1	19	12	53	4.8	1.0	8.6	2.6	1.1	1.7	1.7
Bg2	36–55	4.2	4.9	37	1	4.1	1.0	0.1	0.1	11	13	40	5.8	0.6	9.5	1.8	1.0	1.0	1.0
Cgf	55–100	4.6	5.3	16	1	4.6	1.3	0.1	0.1	9	12	51	3.9	0.4	6.5	1.7	0.9	0.9	0.9
2. Toeslope																			
Oi/Oe	0–27	–	4.4	431	10	6.2	6.6	1.5	0.1	226	41	35	7.7	1.9	9.4	2.4	<0.1	7.2	2.0
Bw/Bg1	27–38	4.1	5.1	32	1	2.8	1.1	0.1	0.1	17	16	24	5.4	1.2	6.3	2.6	0.1	3.7	1.8
Oa'	38–40	–	5.0	154	6	13.4	3.4	0.1	0.1	53	63	27	–	–	–	–	–	–	–
Bgjj	40–53	4.3	5.2	13	1	3.7	1.4	0.1	0.1	10	13	41	5.0	0.8	5.7	2.3	0.1	3.4	2.1
Bg2	53–70	4.3	5.2	15	1	3.7	1.3	0.1	0.1	12	13	40	7.8	0.8	8.4	2.1	0.1	4.5	1.8
Cf	70–100	4.3	5.3	44	2	4.8	1.4	0.1	0.1	15	17	38	9.7	1.0	1.4	2.3	0.1	6.0	2.0
3. Footslope																			
Oi	0–16	–	4.3	464	10	–	–	–	–	122	–	–	–	–	–	–	–	2.2	1.8
Oe/Bg	16–28	3.8	4.6	119	5	6.8	0.9	0.1	0.1	52	42	19	8.8	3.5	9.8	4.9	0.8	8.1	4.2
Oe'/Bg'	28–43	4.1	5.0	181	8	10.0	1.1	0.1	0.1	16	49	23	7.9	4.4	10.2	6.0	0.7	8.6	5.5
Oe"	43–52	4.2	4.8	166	7	15.0	1.7	0.1	0.1	66	63	27	9.6	5.7	11.8	7.1	0.4	10.1	6.5
Bg/Oe	52–70	3.9	4.2	98	4	6.6	0.8	0.1	0.1	51	40	19	6.6	4.2	7.8	5.3	0.6	6.9	5.1
4. Footslope																			
Oi	0–14	–	4.1	473	10	–	–	–	–	216	–	–	–	–	–	–	–	0.1	0.2
Oe	14–18	–	4.0	461	13	–	–	–	–	97	–	–	3.5	2.0	3.5	2.3	<0.1	2.7	2.4
A	18–23	3.5	4.3	126	5	4.2	1.3	0.1	0.1	66	43	13	5.9	2.5	6.6	3.5	0.1	5.3	3.2
Oe'	23–30	3.6	4.1	301	11	5.8	1.4	0.1	0.1	91	68	11	10.9	4.3	12.7	5.5	<0.1	11.4	5.4
Bg/Oa	30–55	3.6	4.1	149	6	2.4	0.5	0.1	0.1	78	48	6	10.6	4.7	13.1	6.2	<0.1	11.4	5.7
5. Backslope																			
Oe	0–15	–	4.2	449	10	16.3	4.9	1.2	0.4	–	111	20	–	–	–	–	–	–	–
Oa	15–19	–	4.2	342	15	18.2	4.4	0.6	0.2	–	100	23	–	–	–	–	–	–	–
Bg	19–40	–	5.7	5	1	5.0	1.5	0.1	0.1	–	10	67	4.7	0.5	5.6	1.5	0.6	1.3	0.7
Crf	40–50	–	6.1	6	1	5.6	1.9	0.1	0.1	–	11	70	6.3	0.7	5.8	1.4	0.5	1.1	0.7
6. Summit																			
Oe	0–11	–	3.7	382	11	8.6	5.9	1.3	0.1	–	84	16	–	–	–	–	–	–	–
A	11–13	–	3.9	90	3	0.5	1.0	0.2	0.1	–	37	5	6.6	1.6	6.3	2.7	0.4	3.6	1.5
Bgjj	13–14	–	4.9	10	1	0.1	tr	tr	tr	–	11	3	5.2	2.0	5.5	3.0	0.4	2.7	2.3
Bwjj1	14–42	–	5.1	15	1	0.2	0.1	tr	tr	–	14	3	5.4	2.5	6.6	4.1	0.5	3.3	3.3
Bwjj2	42–53	–	5.1	9	1	0.1	0.1	tr	tr	–	11	3	5.2	2.1	6.0	3.3	0.4	2.9	2.6
Oajj	13–20	–	4.3	101	4	0.9	0.4	0.1	0.1	–	44	4	7.2	2.6	7.3	4.2	0.1	5.0	3.2
Ajj	26–30	–	4.7	37	1	0.4	0.2	tr	tr	–	25	3	5.5	1.9	6.8	3.0	0.3	3.0	2.3
BC	53–80	–	5.4	20	1	0.5	0.2	tr	tr	–	14	6	6.4	2.5	6.8	3.6	0.6	3.7	3.4
Cf	80–105	–	5.4	10	1	0.6	0.3	tr	tr	–	12	9	5.7	1.7	5.5	2.5	0.5	1.9	1.8
South Catena sites																			
7. Shoulder																			
Oi	0–5	–	5.0	427	23	53.1	9.1	4.0	0.2	41	108	61	3.6	3.0	4.3	3.7	0.2	1.7	3.4
A	5–13	4.0	4.6	46	2	4.8	1.4	0.3	0.1	22	26	25	13.5	2.0	11.8	4.3	1.4	4.9	2.9
EB	13–25	4.3	5.0	10	1	2.5	1.1	0.1	0.1	7	12	31	10.1	0.9	8.5	2.5	1.2	1.5	1.0
Bw	25–63	4.9	5.7	4	1	7.1	3.5	0.1	0.1	5	13	83	10.8	0.8	9.6	2.4	1.5	1.1	0.6
BC	63–100	5.2	6.1	3	1	7.2	3.6	0.1	0.1	6	13	85	11.7	0.9	10.0	2.3	1.3	1.6	0.7
8. Backslope																			
Oi/Oe	0–12	–	5.3	401	16	30.0	9.0	2.0	0.1	37	87	47	6.6	3.7	7.6	4.8	0.7	3.9	3.8
A	12–32	3.9	4.7	53	2	0.7	0.3	0.1	0.1	22	19	6	10.3	2.1	10.0	4.3	1.4	4.7	2.6
2Bw/Ab	32–56	4.2	5.2	6	1	2.3	0.9	0.1	0.1	7	8	41	10.1	1.1	6.8	1.8	0.7	1.7	0.8
2BC	56–92	4.7	5.8	5	1	5.0	1.6	0.1	0.1	5	7	94	8.5	0.7	5.9	1.3	0.7	1.3	0.4
2C	92–100	5.1	6.1	4	1	9.4	2.7	0.1	0.1	4	12	100	12.7	1.1	8.6	1.8	0.9	1.2	0.6
9. Backslope																			
Oi/Oe	0–9	–	3.8	514	8	–	–	–	–	112	–	–	–	–	–	–	–	0.8	1.2
Oa	9–11	–	4.3	483	16	8.9	3.0	0.4	0.1	105	94	13	9.7	4.6	10.4	5.5	0.3	8.7	5.4
A	11–31	3.7	4.2	106	5	1.7	0.5	0.1	0.1	26	21	10	10.1	2.4	7.8	2.9	0.8	4.7	2.2
Bg	31–41	4.2	4.9	8	1	1.9	0.7	0.1	0.1	7	8	33	8.8	1.0	6.3	1.7	0.6	2.2	1.0
Cr	41–61	4.3	4.8	9	1	2.6	0.9	0.1	0.1	9	10	35	9.3	1.0	6.1	1.9	0.6	2.6	1.3
10. Footslope																			
Oi/Oe	0–10	–	4.6	477	21	21.3	6.1	1.7	0.1	78	77	38	7.7	3.5	7.8	4.1	0.5	4.4	3.5
A1	10–25	3.8	4.2	19	1	1.0	0.4	0.1	0.1	17	16	9	10.6	1.5	7.9	2.9	1.0	2.6	1.4
A2	25–32	3.8	4.5	22	1	0.7	0.3	0.1	0.1	17	15	7	10.8	1.7	8.5	3.4	1.2	3.5	2.0
Bw	32–54	4.0	4.7	13	1	0.4	0.2	0.1	0.1	8	9	7	10.5	1.2	8.	2.3	0.7	2.6	1.4
BC	54–73	4.1	4.9	4	1	0.5	0.2	0.1	0.1	5	6	12	10.5	1.0	6.9	1.8	0.7	2.1	1.0
C	73–90	4.8	5.6	2	1	4.9	1.3	0.1	0.1	3	8	79	11.5	0.8	6.5	1.6	0.7	0.8	0.3

† All analytical methods are from Soil Survey Laboratory Staff (1996): pH in 0.01*M* CaCl$_2$ and water, organic C and total N (OC and TN) by LECO analyzer, extractable bases and cation exchange capacity (CEC) by 1*M* NH$_4$OAc pH 7, base saturation = sum of the bases extracted as a percentage of CEC determined, exchangeable acidity by BaCl$_2$–TEA pH 8.2, Fe and Al dissolved by citrate-dithionite (Fe$_d$, Al$_d$); Fe, Al, and silica dissolved by oxalate (Fe$_o$, Al$_o$, and Si$_o$); and Fe and Al soluble by sodium pyrophosphate (Fe$_p$, Al$_p$).

soils tend to have pH values that range from extremely acidic (pH approximately 4.0) in the surface organic horizons to very strongly acidic (pH approximately 5.0) in organic rich mineral subsurface horizons where the exchange complex is buffered mainly by Al derived from the greenschist bedrock. Slightly higher pH values occur in the footslope and floodplain soils (Sites 2 and 1) and reflect limited leaching and conservation of base cations. The pH difference between south and north aspect catena soils represents a threshold transition between an exchange complex dominated by nonhydrolyzed cations such as Ca and Mg to one dominated by Al^{3+}, hydroxyl Al species, and H^+ (Chadwick and Chorover, 2001). Reinforcing this postulation, exchange acidity and CEC are high in these soils, especially in the O horizons. In subsurface horizons, elevated Ca and Mg levels are correlated with OC content ($R = 0.80$, $P = 0.07$ and $R = 0.67$, $P < 0.0001$, respectively), this suggests that both Ca and Mg are complexed with humus. The extractable cations (Ca, K, Mg, and Na) are largely held on exchange sites within the humic fraction of these soils. Soil base saturation values <25% suggest relatively high acid-hydrolytic leaching. The more mineral-dominated south aspect catena soils have lower mean profile OC values, slightly lower CEC, but higher BSat and concentrations of extractable cations than the north aspect catena.

Patterns of Fe and Al ratios (Fe_o/Fe_d and Al_p/Al_o) are different in the north aspect catena upland soils where there is an increasing trend with depth not seen on the south catena. This indicates elemental complexing with SOM and elemental loss through reductive loss of Fe or soluble amorphous Al-organic ligands. In these poorly drained soils, Fe produced by weathering is largely in the ferrous form due to anaerobiosis and is easily reprecipitated by intermittent oxidation or lost in lateral runoff over frozen soil. Even though soil temperature at 50 cm was below freezing (Table 2) during the growing season, Fe reduction was still detectable by the α, α'-dipyridyl field test method (Vepraskas and Sprecher, 1997) in mineral soil horizons. This is not surprising since biologists have found that SOM decomposes at subzero temperatures in boreal and arctic regions (Hobbie et al., 2000) and pedologists found similar results in laboratory incubations (Michaelson and Ping, 2003). The ratio of Fe_o/Fe_d and Al_p/Al_o approaching or exceeding unity in the poorly drained and organic rich soils indicates that the majority of Al and Fe are complexed with humus (Table 4). The greenschist facies parent material supplies abundant Al that readily complexes with humus. Aluminum not complexed with humus is presumed to be in amorphous phases that are easily solubilized and serve as long-term pH buffers (Hsu, 1989). The pedogenic maturity index (Harden and Taylor, 1983) for the poorly-drained north aspect catena and floodplain soils of 1 to 3 and 3 to 5 cmol H^+ kg OC^{-1} m^{-2} for organic and mineral horizons, respectively, indicate that mineral horizons in the north aspect catena are less pedogenically advanced than those of the better drained south aspect catena where values range from 6 to 10 cmol H^+ kg OC^{-1} m^{-2}.

Soil Climate and Soil Classification

Soil classification is a tool for land-based technology transfer at many scales. Management practices for soils can be inferred for soils from other parts of interior Alaska with similar characteristics and properties. Soils in this study were classified using both U.S. Soil Taxonomy (Soil Survey Staff, 2003) and the World Reference Base for Soil Resources (FAO, 1998) to broaden potential applications of the database (Table 5).

Based on data sets from 1995 through 2002 for the CRREL station, mean annual soil temperature (MAST) at 50 cm is −1.8°C, 2.1°C warmer than the mean annual air temperature (MAAT). The average mean summer (June, July, August) soil temperature (MAST) is 5°C warmer than the average mean winter (December, January, February) soil temperature (MWST).

The mean annual precipitation (MAP) measured halfway between the CRREL and Caribou Peak site at 485 m is 359 mm and occurs primarily in summer. On average, frost-free days are 173 and 149 at the CRREL and the Caribou Peak sites, respectively. Depth to permafrost fluctuates between 46 and 80 cm with 64 cm being the average.

Interior Alaska soils have an udic soil moisture regime even though the MAP is only about 300 mm because approximately 47% of the MAP is evenly spread over the growing season (NOAA, 2001). However, aquic soil moisture regimes exist in the lowlands and on the northerly slopes where drainage is restricted due to the presence of permafrost that limits liquid water infiltration. The Caribou Peak Station is situated near the south rim of a broad summit where no permafrost occurs within 4 m of the surface. Here the MAST is 0.4°C, and at the CRREL it is −1.8°C. Such MAST values fall within

Table 5. Soil classification of the soils studied in the Caribou-Poker Creek Research Watershed, Alaska.

Site #	Soil classification (Soil Survey Staff, 2003)	WRB (FAO, 1998)
	North Catena sites	
1	Coarse-silty, mixed, superactive, subgelic Typic Histoturbels	Histic Cryosols
2	Coarse-silty, mixed, superactive, subgelic Ruptic-Histic Aquiturbels	Histic-Turbic Cryosols
3	Dysic, subgelic Lithic Hemistels	Gelic Histosols
4	Dysic, subgelic Lithic Hemistels	Gelic Histosols
5	Loamy-skeletal, mixed, superactive, subgelic, Lithic Aquitubels	Histic Cryosols
6	Coarse-loamy, mixed, superactive, subgelic Aquic Haploturbels	Turbic Cryosols
	South Catena sites	
7	Coarse-loamy, mixed, superactive, subgelic Typic Dystrocryepts	Dystric Cambisols
8	Coarse-loamy, mixed, superactive, subgelic Typic Dystrogelepts	Dystric Cambisols
9	Loamy, mixed, superactive, subgelic Lithic Dystrogelepts	Dystric Cambisols
10	Loamy-skeletal, mixed, superactive, subgelic Humic Dystrogelepts	Dystric Cambisols

the range of the subgelic soil temperature class, (+1 to −4°C) (Soil Survey Staff, 2003) but only those with permafrost are classified as Gelisols (soils affected by permafrost) and those without are Inceptisols. Soils on the summit and shoulder (Site 8) have MAST > 0°C but < 1°C thus keyed into the Cryepts suborder. But most soils on the backslopes and footslopes of the south aspect have a gelic soil temperature regime, thus they are keyed into the Gelepts suborder.

Weakly developed soils without permafrost in the well-drained south-aspect catena are classified as Inceptisols. Typic Dystrocryepts commonly occur on the summits and shoulders, Typic and Humic Dystrogelepts occur on backslopes and footslopes, and Lithic Dystrogelepts occur on the lower backslopes. In the FAO-WRB system, these soils, depending on the depth of gleyed horizons, are classified as Cambisols or Gleysols. Soils of the north-aspect catena and on floodplains with permafrost within 1 m of the surface are Gelisols. Turbels occur in the north-slope catena and floodplains. Turbels experiencing saturation with subsequent reducing conditions during the growing season are classified as Aquiturbels or Ruptic-Histic Aquiturbels, the latter are soils containing discontinuous organic horizons. In the FAO-WRB system, depending on the thickness of the organic horizon, these are either Histic Cryosols or Cryic Histosols, respectively.

Effects of Fire on Soil Properties

Little published information relating fire severity or soil temperature to soil reddening is available especially for cold, young soils similar to those of the watershed, although the authors have frequently noted such phenomenon in the field.

Watershed topography and hydrology dictate the response of the pedogenic environment to fire. The morphology of permafrost-free soils on the south aspect, upland soils (Sites 7, 8, and 9) show little process change due to fire since they already have thin O horizons and are in a conditional steady state with drier conditions. Soils within the coldest and wettest regimes, north aspect catena and floodplains (e.g., Sites 2, 3, 4, and 1), are also less impacted by fire because most of the saturated organic mat and permafrost persists after fire. Marginal soils with permafrost in potentially warmer/drier topographic positions, such as southeast through, southwest aspect slopes (e.g., Sites 7–10) are most likely to show major changes in moisture and temperature regimes after fire (Swanson, 1996).

Interior Alaska boreal forest ecosystems are subject to frequent lightning-caused fires during the summer (Foote, 1983). Fire disrupts ecologic successional trajectories and permafrost dynamics, and, thus is an important factor controlling soil properties (Viereck, 1970; Viereck et al., 1983). The vegetation mosaic and soil morphology observed in this region strongly reflect the combined effects of fire, permafrost, and landscape characteristics. Common evidence of past fires includes accumulations of charcoal particles in soil profiles, especially at the base of the O and throughout the A and upper B horizons. In this region of discontinuous permafrost, vegetation plays an important role in modifying the soil temperature by providing shade and insulation (Van Cleve et al., 1992); hence, destruction of the vegetative cover drastically impacts the soil environment and ultimately, soil properties. Vegetation and topographic position also influence permafrost dynamics. Permafrost persists under "mature" spruce forest canopies and degrades quickly when the soil is exposed to increased solar radiation. After fire reduces the insulating organic horizons, mineral soil is exposed and thaws quickly. However, where the permafrost layer is quite thick, permafrost does not disappear completely—its upper surface recedes to a greater depth and an increase in the thickness of the active layer occurs. Knowledge of vegetation-fire-topography-permafrost interactions permits prediction of the effects of fire on soil properties at both landscape and pedon scales.

A broad effect of fire on soil properties is the modification or acceleration of geochemical processes within the solum due to changes in hydrologic conditions. The removal of the vegetation and some or all of the O horizons deepens the active layer and increases effective overland flow and infiltration. The warmer, drier soil moisture regime changes a soil's characteristics, and, subsequently, the soil classification (Viereck and Dyrness, 1979; Dyrness, 1982; Moore and Ping, 1989). Exposure of mineral soil on the steeper slopes can increase mass movement and erosion.

Leaching regimes are altered by combination of greater surface runoff, increased infiltration into mineral horizons, and reduced capillary transport of soluble salts. Following a fire event, a pulse of available nutrients, previously complexed with SOM, is released into the surrounding environment. Labile and most, if not all, immobile C and N are lost through combustive oxidation of OM to CO_x and NO_x. Cation exchange capacity of surface horizons is attenuated due to the formation of black carbon or charcoal, the most recalcitrant and biogeochemically inactive form of OM.

Severe fires can produce reddened mineral horizons. Such reddened mineral horizons frequently occur in upland soils at the surface and occasionally as a buried horizon. This reddish horizon has negative effects on plant growth because it shows some degree of water repellency and also increases soil hardness from friable to slightly firm or firm on severely burned sites. MacDonald and Huffman (2004) found soil water repellency strongest at sites burned at high and moderate intensity and mostly at or near the surface. Severity of fire depends on the quantity and condition of fuel. Soil and fuel moisture are probably the most important factors controlling soil surface temperatures during a fire; involved are specific heat of ice (permafrost and seasonal frost) of 0.5 cal g^{-1} $°C^{-1}$ heat of melting of 80 cal, specific heat of water of 1.0 cal g^{-1} $°C^{-1}$, and heat of evaporation of 540 cal. Thus, topography not only controls soil characteristics but also fire effects. Reddening of the soil matrix occurs when fire raises the surface temperatures from 200° to ≥ 500°C (Sertsu and Sánchez, 1978; Ulery and Graham, 1993). The high temperatures catalyze rapid oxidative weathering of Fe-bearing soil minerals to maghemite and hematite (Ulery and Graham, 1993), especially in the presence of abundant SOM, and the strong sorption of Fe oxides to the surface or interlayer of micas and clays (Ulery et al., 1996).

CONCLUSIONS

Landform plays the controlling role in soil formation in the boreal region of interior Alaska. The landform factor, acting through slope aspect, redistributes the climatic attributes especially solar energy and precipitation. Thus the south aspect has a cryic soil temperature regime (STR) and udic soil moisture regime (SMR) whereas the north aspect has an aquic SMR and pergelic STR. As a result, different vegetation communities develop on different aspects and feed back to soil formation. Even though the area was not glaciated, the degree of soil formation does not increase with time because of colluvial processed and the constant addition of eolian dust.

The south aspect catena soils formed in a relatively drier, warmer microclimate than north aspects and floodplains and results in thinner and less humified O horizons and thicker mineral horizons with a yellowish hue. The dominant soil processes are brunification and the soils thus formed are classified as Inceptisols. The north aspect catena soils formed in a relatively wetter, colder microclimate that results in increased accumulation of OC and a reducing condition. The thick O horizon contributes to the development and maintenance of permafrost that result in soils commonly being classified as Gelisols.

Pedogenic processes in the CPCRW are readily modified or accelerated by fire, and, a general response is predictable. The reduction or loss of the surface O horizon would result in the deepening of the active layer, prolonged episodes of saturation and reducing conditions, a net decrease of C and N storage and an increase in recalcitrant, non-reactive black carbon. South aspect soils on back slopes can experience increased mass movement and erosion due to the removal of ground cover. Thick O horizons on the north slopes, with high water holding capacities, are relatively insulated from the effects of fire.

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